

Hydrometallurgy in raw materials utilization - an educational and communication programme (HydroMetEC)

Lifelong learning program
(2020-2022)



Metso:Outotec



BOLIDEN



MONOLITHOS
CATALYSTS - RECYCLING - INNOVATION



EIT RawMaterials is supported by the EIT,
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RawMaterials
Connecting matters

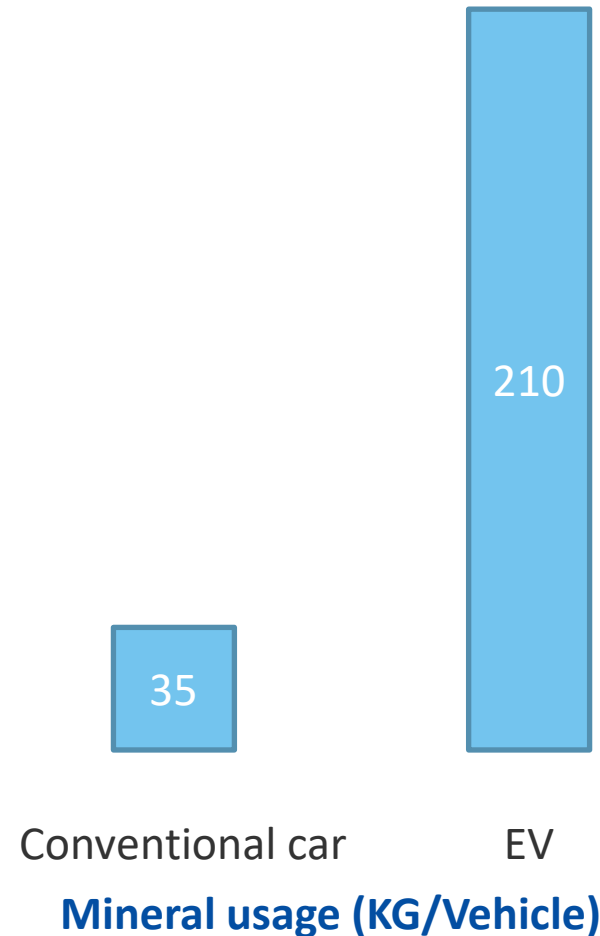
Towards Net Zero, from oil to renewable energy, from oil to minerals usage

Source: IEA

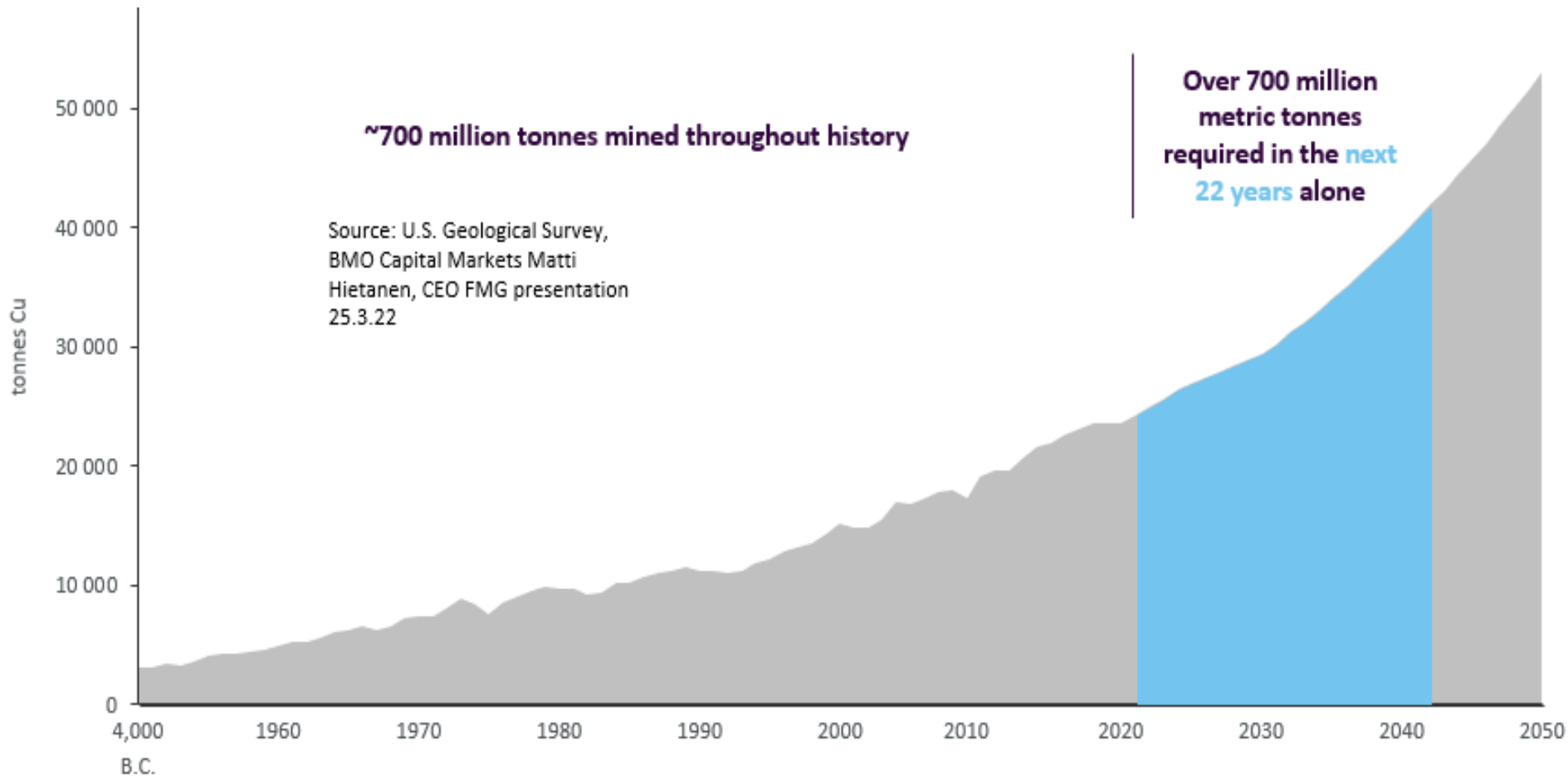
ENERGY SUPPLY

Mineral usage, t/MWh

- Coal (2)
- Natural gas (1)
- Offshore wind (15)
- Onshore wind (10)
- Nuclear (5)
- Solar panel (3)



Mankind has so far mined 700,000,000 tonnes of copper of which 80% is still in use



*“If 2008 was a financial crisis, this is a **molecule crisis**”*

*We’re out of everything,
I don’t care if it’s oil, gas, coal, copper, aluminium, you
name it we’re out of it.”*

And **Hydrometallurgy** is needed
to produce most of the metals
for green energy

Jeff Currie, Global Head of
Commodities Research
Goldman Sachs
February 2022

Cathode:

Al - current collector (5%)

Co, Ni, Li, Mn - active materials (32%)

Binders

Anode:

Cu - current collector (8%)

Graphite (14%)

Separator i.e Porous membranes (3%)

polymers

Electrolyte salts: LiPF_6 , LiBF_4 ... (14%)

Organic solvents: ethylene/dimethyl/diethyl carbonate

Casings: Fe / other metals (polymers) (18%)

(Contamination of other battery types)

Battery content source modified
from F. Larouche et al. Materials
13(3), 801

Photo: Valeria Azovskaya

Upcoming EU battery regulation

- Transparent information about the recycled content required
- 2030: Minimum required recycled contents in battery: 4% Li, 4% Ni, 12% Co
- 2035: Minimum required recycled contents in battery: 10% Li, 12% Ni, 20% Co
- Element specific requirements for recycled amount of Li, Cu, Ni, Co

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More mining and refining needed!

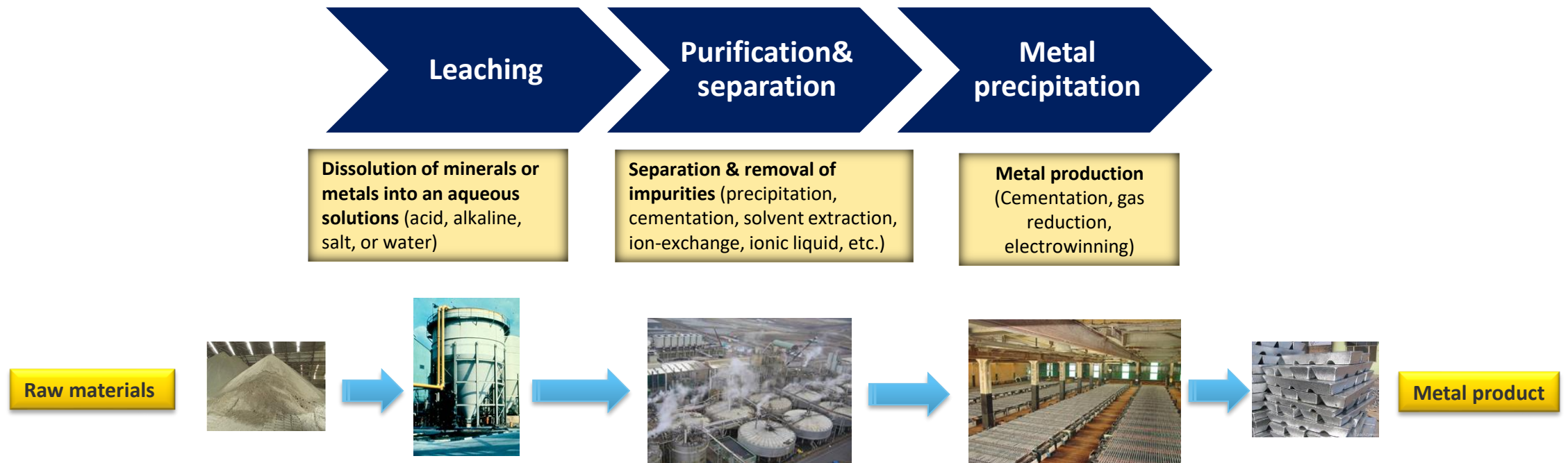
Recycling development needed!

- Recycling can fulfill <10% of raw material needs for batteries 2030
- 2040 already almost 50% of battery materials can be achieved by recycling
- 2050 ~80% of battery nickel and cobalt can be achieved by recycling

Hydrometallurgy

One of the three metallurgical technologies (Pyro-, Hydro- and Electrometallurgy)

3 types of unit operations



Hydrometallurgy



Advantages

- High selectivity over certain minerals or metals
- Suitable for low grade or complex ores, solid waste
- Flexibility and high modularity
- Efficient for removal of the harmful species and recovery of valuable metals
- Lower energy consumption in many cases and thus a low CO₂ emissions
- Lower capital and operational costs compared to pyrometallurgical processes

Limitations

- Lower productivity, and complex flowsheet
- Generation of large amount of effluent and solid residues
- Sometimes higher energy consumption in particular for sulphide concentrates

Applications of hydrometallurgy

Primary metals extraction and refining – mature technologies

- **Zinc** production (80%): roasting - leaching – electrowinning (RLE)
- **Copper** extraction (20%): leaching - solvent extraction - electrowinning (SX-EW process)
- **Aluminium**: alumina refining from bauxite (100%) - Bayer process
- **Nickel & nickel - cobalt** separation
- **Gold** production - cyanidation process: leaching - electrowinning
- **REE** extraction: leaching of REE minerals for RE oxide production (in combination with pyro- and electrometallurgy)
- **Uranium**: Na_2CO_3 based leaching process for U extraction.

Metals Recycling - emerging

- Industrial residues, EoL products and various types of scrap
- Already used for refining after pyrometallurgical processing



Organisation of the events in the project

Introductory course

Fundamental knowledge about hydrometallurgical processes and typical unit operations and industrial applications

Advanced course

Important and advanced processes for the industrial applications

International seminar

Challenging issues in hydrometallurgical processing, sustainability, value chain in metals production and supply

Introductory course 2020
Norway - Online

Advanced course 2020
Sweden - Online

International seminar
2020, Sweden - Online

Introductory course 2021
Netherlands - Online

Advanced course 2021
Finland - hybrid

International seminar
2021, Finland - hybrid

Introductory course 2022
Finland - hybrid

Advanced course 2022
Greece - hybrid

International seminar
2022, Greece - hybrid



Life Long Learning Course: *HydroMetEC*

- *Hydrometallurgy in raw materials utilization*

- an educational and communication programme

Part II: Advanced Course and Seminar

Hosted by National Technical University of Athens, Mytilineos and Monolithos in Athens, Greece

Join us for a 2-day hybrid advanced course in hydrometallurgy, from **21-22 November**, given by recognized academia and industrial experts. The course will include lectures on topics such as:

- ✓ Mass and energy balance in hydrometallurgy
- ✓ Kinetics and thermodynamics in hydrometallurgy
- ✓ Applications

A visit to Monolithos PGM recycling and catalyst production facilities. This will include lectures, tour and laboratory demonstrations

This will be followed by a 2-day hybrid seminar from **23-24 November** featuring:

1-day plant visit to Mytilineos Alumina production plant outside Athens. This will include a comprehensive plant tour and lectures on the Bayer process (only physical attendees).

1-day seminar featuring talks and workshop on critical raw materials (CRMs).



Register at: <https://ntnu.eventsair.com/hydrometec-2022/advanced>
Deadline for registration: 11 November 2022
For more information: <https://www.ntnu.edu/metpro/hydrometec>

Registration fees: Advanced course (€60) and Seminar (€60).

Who should attend?

Participants from industry (engineers, scientists, researchers, technologists) and academia (postgraduate students and postdoctoral researchers) are welcome. A background in bachelor level chemistry/materials science/geology or attendance to the Introduction to Hydrometallurgy course is required.





Schedule: Advanced course in Hydrometallurgy

Hybrid 21-22 Nov 2022

08:45-09:00	Opening Remarks	
Day 1: Monday 21-11-2022		Lecturer
09:00-09:45	Advances in Understanding of the Hydrometallurgical Unit Operations in Non-Ferrous Extractive Metallurgy	<u>Srećko Stopic</u> – Invited Speaker (RWTH Aachen)
10:00-10:45	Sustainable agitator and reactor design for demanding applications in hydrometallurgy	Tuomas Hirsi (Metso Outotec)
11:00-11:30	Coffee Break	
11:30-12:15	Thermodynamics in hydrometallurgy	Mari Lundstrom (Aalto)
12:30-13:15	Hydrometallurgical circuits	Yongxiang Yang (TU Delft)
13:15-14:15	Lunch	
14:15-15:00	Alkaline electrolysis in iron ores	Panias Dimitrios (NTUA)
15:15-16:00	Kinetics in hydrometallurgical processes I	<u>Jafar Safarian</u> (NTNU)
16:15-16:45	Coffee Break	
16:45-17:30	Kinetics in hydrometallurgical processes II	<u>Jafar Safarian</u> (NTNU)
Day 2: Tuesday 22-11-2022		
Thematic Session: Greek Metals Recycling – Industrial Cases		
09:00-09:45	Secondary Lead Production from Spent Lead Acid Batteries	Athanasios Karakatsanis (<u>Sunlight Recycling S.A.</u>)
10:00-10:45	Challenges in Copper Recycling in the Semi-Fabricators' Industry	Nikolaos Marinakis (<u>Halcor</u>)
11:00-11:45	The TETALEAD process	Lena Sundqvist (LTU)
11:45-13:00	Lunch	
13:00-14:00	Transportation from NTUA	MONOLITHOS
14:00-14:45	MONOLITHOS hydrometallurgical process presentation	MONOLITHOS
14:45-15:30	MONOLITHOS catalyst synthetic protocol for substituting CRMs	MONOLITHOS
15:30-16:30	Lab tour demonstrating the aforementioned procedures	MONOLITHOS
16:30-17:30	Cocktails for participants	MONOLITHOS



Schedule: International seminar

Hybrid 23-24 Nov 2022



Day 1: Wednesday 23-11-2022 (Host: <u>Mytilinaios S.A.</u>)		
07:00-09.45	Transportation from Athens to Seminar Venue (near the <u>Mytilinaios</u> industrial facilities)	
Thematic Session: Primary Aluminium Production		Lecturer
10:00-10:15	Opening Remarks	Mytilinaios S.A. Executive Personnel
10:15-11:00	Bauxite Mining	
11:15-12.00	Alumina Refining from Bauxite (The Bayer Process)	
12:15-12:45	Coffee Break	
12:45-13:30	Electrolytic Reduction of Alumina	Mytilinaios S.A. Executive Personnel
13:45-14:30	Bauxite Residue Handling and Reuse Potential (The Greek BR case)	
14:30-15:30	Lunch Break	
15:30-16:30	Field trip to <u>Mytilineos S.A.</u> plant	Efthymios Balomenos
16:30-19:15	Transportation from <u>Mytilinaios S.A.</u> plant to Athens	
Day 2: Thursday 24-11-2022		
Thematic Session: CRM extraction technologies by hydrometallurgical routes		
09:00-09:45	Lithium Ion Batteries (LIBs) recycling	Prof. Anthimos <u>Xenidis</u> , NTUA
09:45-10:15	Discussion	
10:15-11:00	Invited Speaker 2: Title Pending	Dr. Olga Chernoburova, University of Lorraine
11:00-11:30	Discussion	
11:30-12:00	Coffee Break	
12:00-12:45	Alternatives to Bauxite for Alumina Production – Dream or Potential?	Michail Vafeias, NTUA
12:45-13:15	Discussion	
13:15-14:30	Lunch Break	
14:30-15.15	Bauxite Residue as a potential Sc and REE source – Pilot Scale Research Highlights	Efthymios Balomenos, <u>Mytilinaios S.A.</u>
15:15-15:45	Discussion	
15:45-16.30	Acid leaching for high purity Si production from the innovative <u>SisAl</u> process	Mengyi Zhu
16:30-17:15	Discussion	NTNU

Hybrid (Physical and Online) (Central European Time)

Tuesday 03-05-2022	Module 1: Fundamentals of hydrometallurgy	Lecturer
08:45-09:00	Welcome address by host	Mari Lundström/Aalto
09:00-09:45	Hydrometallurgy and its applications in metals production: an overview	Yongxiang Yang/TU Delft
09:45-10:30	Metal resources for hydrometallurgical extraction and recycling	Mari Lundström/Aalto
10:30-10:45	Coffee Break	
10:45-11:30	Leaching (atmospheric-, pressure-, bio-, organic lixivants)	Mari Lundström/Aalto
11:30-12:00	Exercise 1 (Leaching)	Sipi Seisko/Aalto
12:00-13:15	Lunch Break	
13:15-14:00	Separation and solution purification -1: precipitation method	Lena Sundqvist/LTU
14:00-14:45	Separation and solution purification -2: solvent extraction and ion exchange	Lena Sundqvist/LTU
14:45-15:00	Coffee Break	
15:00-15:30	Exercise 2 (Separation)	Lena Sundqvist/LTU
Wednesday 04-05-2022	Module 1: Fundamentals of hydrometallurgy	Lecturer
09:00-09:45	Metals recovery: cementation and hydrogen reduction	Yongxiang Yang/TU Delft
09:45-10:30	Metals recovery and refining: electrowinning and electro-refining	Jari Aromaa/Aalto
10:30-10:45	Coffee Break	
10:45-11:15	Exercise 3 (electrowinning and electro-refining)	Jari Aromaa/Aalto
11:15-12:00	Solid - Aqueous interface properties in hydrometallurgy	Efthymios Balomenos/MYTILINEOS
12:00-13:15	Lunch Break	
	Module 2: Battery metals production	Lecturer
13:15-14:00	Application of hydrometallurgy in primary production of battery metals (Outotec Lithium Process)	Marika Tiihonen/Metso Outotec Finland Oy
14:00-14:45	Application of hydrometallurgy in primary production of battery metals (nickel and cobalt)	Zac Komur/Northvolt AB
14:45-15:00	Coffee Break	
15:00-15:45	Application of hydrometallurgy in recycling of battery metals	Madeleine Scheidema/Metso Outotec Finland Oy
15:45-16:30	Environmental impacts of hydrometallurgical battery recycling processes	Marja Rinne/Aalto

Tuesday 10-05-2022	Module 3: Application and practice	Lecturer
08:30-09:15	Application of hydrometallurgy in production of copper	Yongxiang Yang/TU Delft
09:30-10:15	Application of hydrometallurgy in alumina production: Bayer process	Efthymios Balomenos/MYTILINEOS
10:30-11:15	Application of hydrometallurgy in production of zinc	Dennis Kemperman/Nyrstar Budel
11:30-12:15	Electrorefining of copper at Boliden Harjavalta	Topias Härmä/Boliden Harjavalta
12:15-13:30	Lunch Break	
13:30-14:15	Application of hydrometallurgy in production of nickel	Rauno Luoma/Nornickel Harjavalta
14:30-15:15	Basics of electrodeposition – redox replacement	Kirsi Yliniemi/Aalto
15:30-16:15	Application of hydrometallurgy in production of REEs	Dimitris Panias/NTUA
Wednesday 11-05-2022	Module 3: Application and practice	Lecturer
08:30-09:15	Application of hydrometallurgy in the recycling of PGMs	Anastasia-Maria Moschovi/Monolithos
09:30-10:15	Electrochemical recycling of REEs from NdFeB magnet wastes	Prakash Venkatesan/ULB
10:30-11:15	Application of hydrometallurgy in production of titanium dioxide (synthetic rutile)	James Mwase /NTNU
	Module 4: Laboratory demonstrations	
11:30-12:15	Sampling and materials characterization	Jafar Safarian /NTNU
12:15-13:30	Lunch Break	
13:30-14:00	Hydrometallurgical leaching and nano-catalysts synthesis and characterization	Sotiria Papagianni/Monolithos
14:00-14:30	Extraction of lithium from primary resources	Simon Hellgren/LTU
14:30-15:00	Closing Remarks	Mari Lundström/Aalto

Concluding remarks

- Hydrometallurgy is a flexible and efficient technology, already used in many non-ferrous metals production and refining.
- It is being used more and more for treatment of low grade and complex ores, and secondary raw materials.
- Hydrometallurgy can be effectively used for rare and scarce metal recovery from concentrated or dilute waste streams from waste materials in recycling industry.
- Hydrometallurgy dominates the world zinc production, and will be playing more important role in metals production from both primary and secondary resources.
- Sometimes, a combined route of pyro- and hydrometallurgical processing is more efficient and the best option!

- **Hydrometallurgy is a fascinating world of process metallurgy!**